



Research report:

Construction Site Layout Planning:

(The Collided Bodies/ Enhanced Collided Bodies Algorithms)

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Justification of the choice of the subject:

A suitable facility layout is with no doubt a key to efficient production that should be considered in the earlier stages of a project. A good layout might boost the efficiency and the effectiveness of the works.

The objective is to arrange the temporary facilities such as the job office, the warehouse or the labor residence in a way that maximum design quality is achieved and the total cost of interactions among these facilities is minimized. An effective construction site layout planning is of the utmost importance for the success of any construction project.

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I. Introduction:

Suitable facility layout is believed to be the heart of efficient production that should be considered early in the planning phase. An appropriate construction site layout boosts the effectiveness and efficiency of the works. However, the arrangement of site facilities is hindered by many constraints such as limitations on the site area, adjacent buildings, access, the location and orientation of the building to be constructed.

A Construction site layout problem can be modeled as a quadratic assignment problem (QAP) when the costs associated with flow between departments are assumed to be linear with respect to distance traveled and quantity of the flow. QAP problems are known as non-polynomial hard problems and because of the combinatorial complexity, these cannot be solved exhaustively for reasonably sized layout problems. As an example, for n facilities, the number of possible alternatives, that is the number of feasible configurations, is $n!$ with larger growth than e^n . Even for a small n . For 10 facilities, the number of possible alternatives is already well over 3,628,000. For 15 facilities, we are already in the 12-digit numbers. In real problems, a project with $n=15$ can be considered as a small project. Due to the complexity of the site layout problems, numerous techniques have been proposed to find solutions to these problems; however, it is very difficult to obtain an optimal one suitable for hand calculations. Thus, optimization techniques seem to be suitable means to search for solutions of the site layout problems.

In this research, two recently developed metaheuristic algorithms, known as colliding bodies optimization (CBO) and Enhanced colliding bodies optimization (ECBO), are applied to the solution of construction site layout problems. Colliding Bodies Optimization is developed by Kaveh and Mahdavi and Enhanced Colliding Bodies Optimization is presented by Kaveh and Ilchi Ghazaan. CBO and ECBO

are employed for solution of the CSLP problem and results are compared with those of some previous algorithms.

II. Construction Site Layout Problem

Construction site layout planning problems can be modeled as a QAP (Quadratic Assignment Problem) in which costs associated with the flow between facilities are linear with respect to the distance traveled and quantity of the flow. The objective of construction site layout planning is to assign a number of predetermined facilities (n) uniquely into a number of predetermined locations (m) where the number of locations should be equal or greater than number of facilities. If the number of predetermined locations (m) is greater than the number of predetermined facilities (n), then $(m-n)$ facilities can be added to make both numbers equal. By assigning both the distance and frequency as 0, the facilities added will not affect the layout results.

If each of the predetermined places is capable of accommodating any of the facilities, then the facility layout problem can be modeled as an equal-area facility layout problem. If some of the predetermined places are only able to accommodate some of the facilities, then the problem becomes an unequal-area facility layout problem, where predetermined places have differing areas. Generally, unequal-area layout problems are more difficult to solve than equal-area layout problems, primarily because unequal-area layout problems introduce additional constraints into the problem formulation.

1. Objective function:

The objective function of several models given in the Table below takes the general form:

$$\text{Minimize } F = \sum_{i=1}^n \sum_{j=1}^n W_{ij} * d_{ij}$$

Where:

- F is the objective function and n is the number of facilities and locations.
- Coefficient W_{ij} represents either the actual transportation cost per unit distance between facilities i and j (taking into consideration the number of trips made) or a relative proximity weight that reflects the required closeness between facilities i and j .
- d_{ij} is the distances between facilities i and j

No.	Pseudo model of the objective function
1	To minimize the frequency of trips made by construction personnel
2	To minimize the total transportation costs of resources between facilities
3	To minimize the cost of facility construction and the interactive cost between facilities
4	To minimize the total transportation costs of resources between facilities (presented through a system of proximity weights associated with an exponential scale)
5	To minimize the total transportation costs of resources between facilities and the total relocation costs (presented through a system of proximity weights and relocation weights)

Different kind of objective functions in the previous researches

2. Layout representation:

Each layout alternative can be represented by a $n \times n$ permutation matrix (A permutation Matrix is a square matrix that has exactly one entry of 1 in each row and each column and 0s elsewhere), where n is

the number of facilities or locations, whose rows and columns represent facilities and locations, respectively. The permutation matrix allows a single entry of one in each row and each column, with all remaining entries being zero. The table below shows an example of a permutation matrix with 8 facilities and 8 locations.

Each layout alternative can be represented by a $n \times n$ permutation

	L1	L2	L3	L4	L5	L6	L7	L8	L9
F1	0	0	0	1	0	0	0	0	0
F2	1	0	0	0	0	0	0	0	0
F3	0	0	0	0	0	1	0	0	0
F4	0	0	0	0	0	0	1	0	0
F5	0	0	0	0	0	0	0	1	0
F6	0	0	0	0	0	0	0	0	1
F7	0	1	0	0	0	0	0	0	0
F8	0	0	0	0	1	0	0	0	0

Where L_i is the i^{th} location and F_j is the j^{th} facility.

A specific solution to the site layout problem as shown by the table above is a very sparse matrix and would therefore consume unnecessary computing resources if it is used for large and practical problems. Therefore, because of the property of one-to-one correspondences between facilities and locations, a sequence of integers can be used as a more efficient alternative, like that:

F1	F2	F3	F4	F5	F6	F7	F8
2	7	8	1	5	4	6	3

Each position or entry in the sequence represents a facility; the integer number in the entry represents the location to place the corresponding facility. However, the sequence-based representation may lead to infeasible solutions where multiple entries in the sequence have the same integer number, specifically, the situation of overlay, when adopting the metaheuristic methods. Therefore, some modifications should be made to overcome this difficulty.

III. Metaheuristic Algorithms

To solve construction site layout problems, we use two newly created metaheuristic algorithms, the colliding bodies optimization and the enhanced colliding bodies optimization.

1. Colliding Bodies Optimization

Colliding Bodies Optimization (CBO) is an efficient metaheuristic optimization algorithm that is based on one-dimensional collisions between bodies. All of the following explanations about this method, including definitions and formulas, are extracted from Kaveh and Mahdavi who presented this method.

In this method, one object collides with the other object, and they move toward a minimum energy level. Collisions between these objects are governed by two laws of physics: momentum law and energy law.

Each solution candidate X_i containing a number of variables ($X_i = \{X_{ij}\}$) is considered as a colliding body. The objects have assigned masses and are divided into two equal groups: stationary and moving objects, where the moving objects move to follow stationary objects and a collision occurs between pairs of objects. This takes place for two purposes:

- To improve the locations of moving objects
- To push stationary objects toward better locations

After the collision, new locations of colliding bodies are updated based on the new velocities using collision laws.

The Colliding Bodies algorithm can be briefly presented in the following 7 steps:

Step 1: Initialization

The algorithm starts with a random initial population of agents (CBs) in an m-dimensional search space by the following formula:

$$x_i^0 = x_{min} + rand^0(x_{max} - x_{min})$$

Where:

- x_i^0 determines the initial value vector of the i th CB.
- x_{max} and x_{min} are the minimum and the maximum allowable value vectors of variables.
- $rand$ is a random number in the interval $[0, 1]$.
- n is the number of colliding bodies.

Step 2: Defining Mass

Each colliding body (CB), X_i , has a specified mass defined as:

$$mk = \frac{\sum_{i=1}^n \frac{1}{fit(i)}}{fit(k)}$$

Where:

- $fit(k)$ represents the objective function value of the i^{th} CB.
- n is the number of colliding bodies.

Step 3: Creating groups

Objective function values are arranged in an ascending order. The sorted CBs are divided into two equal groups:

- The lower half of the CBs are stationary CBs that have lower objective function values. These CBs are considered as good agents.
- The CBs of the upper half are moving ones. These CBs move toward the lower ones and then the agents with upper value of each group collide together.

Step 4: Criteria before the collision

The initial velocities of stationary CBs are equal to:

$$v_i = 0, i = 1, 2, \dots, \frac{n}{2}$$

The velocities of moving CBs before collision are equal to:

$$v_i = x_{i-\frac{n}{2}} - x_i, i = \frac{n}{2} + 1, \frac{n}{2} + 2, \dots, n$$

Where:

- v_i and x_i are the velocity and location vector of the i th CB in this group, respectively
- $x_{i-n/2}$ is the i^{th} CB pair location of x_i in the previous group.

Step 5: Criteria after the collision

After the collision, the velocity of stationary CBs (V_i') are specified by:

$$v_i' = \frac{(m_{i+\frac{n}{2}} + \varepsilon m_{i+\frac{n}{2}})v_{i+\frac{n}{2}}}{m_{i+\frac{n}{2}} + m_i}$$

where ε is the coefficient of restitution (COR) that decreases linearly from unity to zero.

$$\varepsilon = 1 - \frac{iter}{iter_{max}}$$

where $iter$ and $iter_{max}$ are the current iteration number and the total number of iterations for optimization process, respectively.

Step 6: Updating the Colliding Bodies

New locations of the CBs are evaluated using their velocities after the collision. The new locations of stationary CBs are:

$$x_i^{new} = x_i + rand^{\circ} v_i'$$

Where:

- x_i^{new} , x_i , and v_i' are the new location, previous location, and the velocity after the collision of the i^{th} CB, respectively.
- $rand$ is a random vector uniformly distributed in the range of $[1,1]$.
- The sign $^{\circ}$ denotes an element-by-element multiplication.

Step 7: Termination criterion check

The process of CBO algorithm is repeated from Step 2 until a termination criterion, such as maximum iteration number, is satisfied.

2. Enhanced Colliding Bodies Optimization:

Enhanced Colliding Bodies Optimization (ECBO) is a new version of the CBO which improves the CBO to get faster and to obtain more reliable solutions. Unlike CBO, the main feature of the ECBO is that it uses a memory to save some best solutions that cause an increase in the convergence speed of ECBO with respect to standard CBO. In order to improve the exploration capabilities of the CBO and to prevent premature convergence, ECBO utilizes a mechanism to escape from local optimal.

All of the following explanations about this method, including definitions and formulas, are extracted from the works of A. Kaveh and I. Ghazaan.

In order to introduce the ECBO, the following steps are developed:

Step 1: Initialization

The algorithm starts with a random initial population of agents (CBs) in an m-dimensional search space by the following formula:

$$x_i^0 = x_{min} + rand^o(x_{max} - x_{min})$$

Step 2: Defining mass

The value of mass for each CB is evaluated according to the same equation as before.

Step 3: Saving

In this step, colliding memory (CM) is utilized to save a number of historically best CB vectors and their related mass and objective function values with the aim of improving the algorithm's performance. At each iteration, solution vectors that are saved in the CM are added to the population and the same number of the current worst CBs are deleted. Finally, CBs are sorted according to their masses in a decreasing order.

Step 4: Creating groups

The CBs are divided into two equal groups according to their objective function values: stationary and moving group.

Step 5: Criteria before the collision

The velocities of the stationary and moving bodies before collision are evaluated by the same equations used in the CBO.

Step 6: Criteria after the collision

The velocities of the stationary and moving bodies after collision are evaluated by the same equations used in the CBO.

Step 7: Updating CBs

The new location of each CB is evaluated by Equation used in step 6 of the CBO.

Step 8: Escape from local optimal

In order to escape from local optimal, a parameter like *Pro* within (0, 1) is introduced, which specifies whether a component of each CB must be changed or not. For each colliding body *Pro* is compared with rn_i ($i=1,2,\dots,n$) which is a random number uniformly distributed within (0, 1). If $rn_i < pro$, one dimension of the i^{th} CB is selected randomly and its value is regenerated as follows:

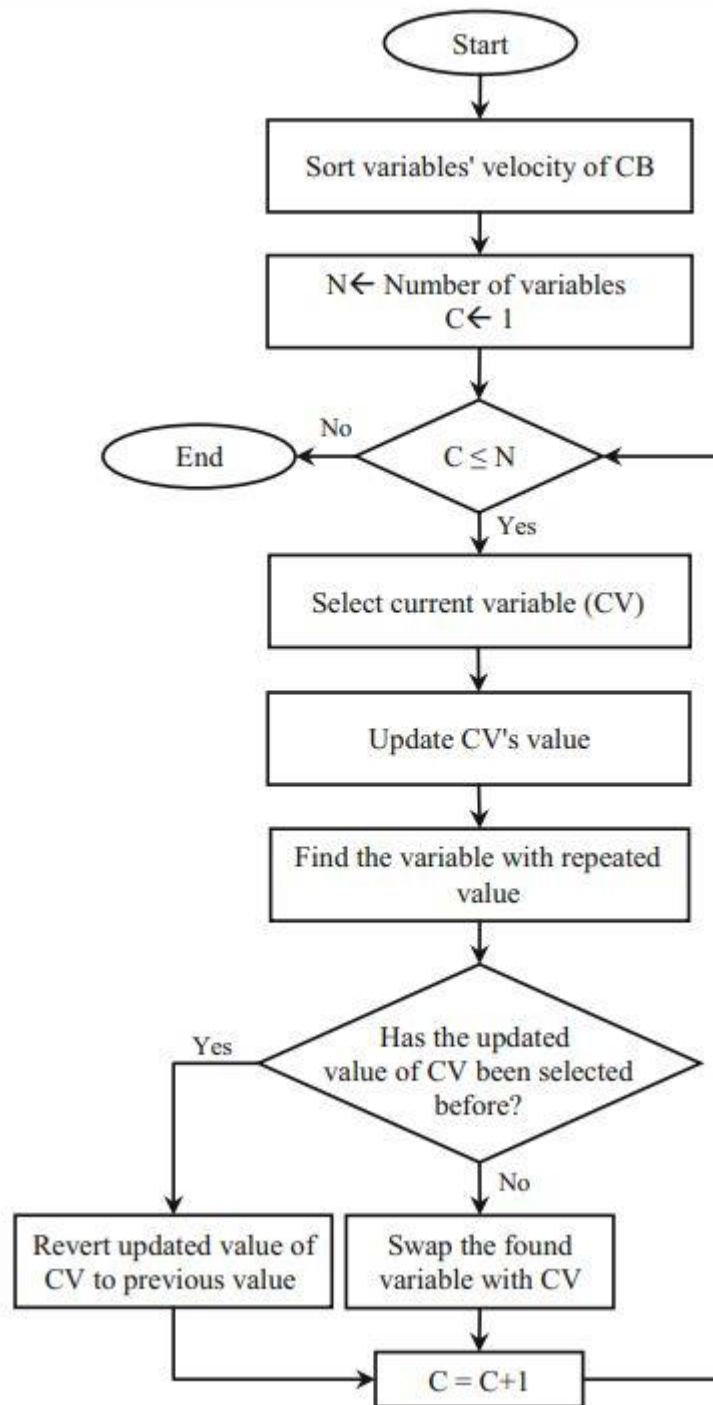
$$x_{ij} = x_{j,min} + random * (x_{j,max} - x_{j,min})$$

Step 9: Termination criterion check

After the predefined maximum iteration number, the optimization process is terminated. If this criterion is not satisfied, go to Step 2 for a new round of iteration.

IV. Discussion of the results

In CBO and ECBO algorithms, each solution candidate X_i containing a number of variables is considered as a colliding body. Each CB is considered as a sequence of variables that represents a layout solution and different sequences mean different layout solutions. Each variable in the sequence represents a facility, and the value of variable indicates the location that is assigned to the corresponding facility. Since every location is capable of receiving only one facility, the CBs should not have duplicated values; violation from this point generates infeasible solutions. However, all the variables of a CB in CBO and ECBO are independent of each other; thus, updating the velocity and position of a CB is performed independently. Therefore, more than one variable in an updated CB may have the same value. Thus, some modifications in updating mechanism should be performed to overcome this infeasibility. The updating mechanism of the CBs is explained in the following:



V. Case Study

To show the applicability and performance of the CBO and ECBO algorithms for construction site layout optimization a case study is shown below. Their results are compared of those of the PSO (Particle Swarm Optimization – a classic optimization method) The algorithms are coded in MATLAB R2011a, and the experiments are

performed on a personal computer with Intel®Core™ i7 processor (1.73 GHz) and 4 GB RAM under the windows 10 Home 64-bit operating system. Parameter values used in these case studies are shown in the table below:

PSO	CBO	ECBO
Population size: 50 Inertia Weight:0,4-0,9 C1=C2: 2	Population size: 50	Population size: 50 CM Size: 5 Pro: 0,3

Results are as follows:

This case study is a medium-sized project and is taken from Li and Love. The purpose of this problem is to find the most appropriate arrangement for placing 11 facilities into 11 predetermined locations on the site. The 11 facilities and their corresponding index numbers. In this case study are shown in the table below:

Index number	Site facilities	Note
1	Site office	Not fixed
2	False work workshop	Not fixed
3	Labor residence	Not fixed
4	Storeroom 1	Not fixed
5	Storeroom 2	Not fixed
6	Carpentry workshop	Not fixed
7	Reinforcement steel workshop	Not fixed
8	Side gate	Fixed to 1
9	Electrical, water, and other utilities control room	Not fixed
10	Concrete batch workshop	Not fixed
11	Main gate	Fixed to 10

For the construction site layout selection, two assumptions are made:

- Each of the predetermined locations is capable of accommodating any of the facilities.
- The main gate and side gate are treated as special facilities, which have been fixed on the predetermined locations.

Objective function:

The objective of this case is to minimizing the total traveling distance of site personnel between facilities:

$$\text{minimize } TD = \sum_{i=1}^n \sum_{j=1}^n \sum_{l=1}^n \sum_{k=1}^n x_{ik} x_{jl} f_{ij} d_{kl}$$

With: $\sum_{i=1}^n x_{ij} = 1$, $\sum_{j=1}^n x_{ij} = 1$

Where:

- n is the number of facilities, in this case $n=11$.
- $x_{ik}=1$ if the facility i is assigned to the location k and equals 0 otherwise.
- x_{jl} is defined similarly.
- Coefficient f_{ij} is the frequency of trips made by construction personnel between facilities i and j per day.
- Coefficient d_{kl} is the distances between the locations k and l .

Distances between site locations:

Location	1	2	3	4	5	6	7	8	9	10	11
1	0	15	25	33	40	42	47	55	35	30	20
2	15	0	10	18	25	27	32	42	50	35	35
3	25	10	0	8	15	17	22	32	52	55	45
4	33	18	8	0	7	9	14	24	44	49	53
5	40	25	15	7	0	2	7	17	37	42	52
6	42	27	17	9	2	0	5	15	35	40	50
7	47	32	22	14	7	5	0	10	30	35	40
8	55	42	32	24	17	15	10	0	20	25	35
9	35	50	52	42	37	35	30	20	0	5	15
10	30	45	55	49	42	40	35	25	5	0	10
11	20	35	45	53	52	50	40	35	15	10	0

Trip frequencies between the facilities:

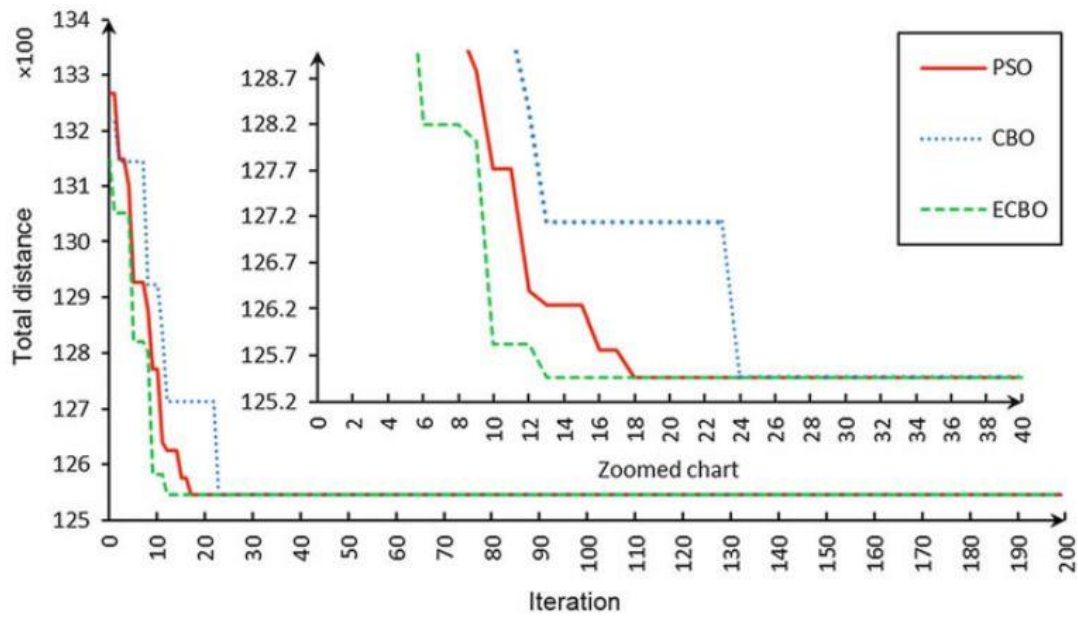
Location	1	2	3	4	5	6	7	8	9	10	11
1	0	5	2	2	1	1	4	1	2	9	1
2	5	0	2	5	1	2	7	8	2	3	8
3	2	2	0	7	4	4	9	4	5	6	5
4	2	5	7	0	8	7	8	1	8	5	1
5	1	1	4	8	0	3	4	1	3	3	6
6	1	2	4	7	3	0	5	8	4	7	5
7	4	7	9	8	4	5	0	7	6	3	2
8	1	8	4	1	1	8	7	0	9	4	8
9	2	2	5	8	3	4	6	9	0	5	3
10	9	3	6	5	3	7	3	4	5	0	5
11	1	8	5	1	6	5	2	8	3	5	0

Results:

This example is solved by carrying out 50 independent optimization runs through 200 iterations to obtain statistically significant results by PSO, CBO, and ECBO. Results returned are:

Algorithm	Best	Average	Worst	Standard deviation
PSO	12,546	12,56	12,756	47,39
CBO	12,546	12,558	12,768	45,51
ECBO	12,546	12,555	12,746	32,11

As it can be seen from this table, the average, worst, and standard deviation for ECBO are: 12,555, 12,746, and 32.11, respectively, which are better than those of CBO and PSO. This indicates that ECBO not only finds a better best solution, but also it is more stable. The convergence curves for the ECBO, CBO, and PSO in terms of the number of iterations are shown in the figure below:



VI. Conclusion

In the study above the application of two recently developed metaheuristic algorithms, CBO and ECBO, is introduced to solve construction site layout problem. The governing laws of physics initiate the base of the CBO and ECBO algorithms, where these laws determine the movement process of the objects. CBO utilizes simple formulation to find minimum of objective functions and does not depend on any internal parameter. In order to improve the exploration capabilities of the CBO and to prevent a premature convergence, ECBO uses a mechanism to escape from local optimal. The latter also uses a Colliding Memory to save a number of the so far best solutions to reduce the computational cost. To validate the models, a case study is considered. The result verify that the proposed approach performs very well both in finding better results and using lower number of evaluations to find the optimum. Comparison of the results with some other well-known metaheuristics shows the suitability and efficiency of the utilized algorithms in CSLP. The proposed algorithms are highly competitive with other metaheuristic algorithms in quality of solutions and convergence speed.

VII. Implementation in Morocco:

After all that a question might come to mind, is this optimization method applicable in Morocco?

A brief and simple answer is yes, it is applicable and its application is quite easy and simple.

In fact, using the 2 metaheuristic Algorithms presented in this research; the CBO and the ECBO isn't a complicated task neither an expensive one, the proposed algorithms work in almost the same way as those already used in Morocco so engineers and technicians must have enough knowledge to make it work, and like said before it will boost efficiency and effectiveness and minimize the cost, and with these being the main objectives of the work of an engineer I think it is worth it to apply this in Moroccan construction sites.

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